Cerebral oximetry and stroke distance: the future of emergency department monitoring?

I Sammy, J Hanson, M R James

Abstract

***Objective*—To illustrate the possible role of cerebral oximetry and stroke distance as measured by Doppler ultrasound in monitoring the critically ill patient non-invasively in the emergency department.**

***Methods*—Five critically ill patients were monitored with either cerebral oximetry or both cerebral oximetry and stroke distance (the distance travelled by blood in the aorta with each ventricular contraction), as measured by Doppler ultrasound of the aortic arch.**

***Conclusions*—Stroke distance as measured by Doppler ultrasound was a good clinical indication of reduced stroke volume and hence of cardiac output. Cerebral oximetry appears to be a useful measure of tissue hypoxia in patients in whom pulse oximetry is either unrecordable or unreliable.**

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Key terms: cerebral oximetry; stroke distance; Doppler ultrasound; non-invasive monitoring

Tissue oxygenation and central haemodynamics are recognised indicators of the clinical state of the critically ill patient. Pulse oximetry is an established means of measuring tissue oxygenation, but may be unreliable or unrecordable in the critically ill patient with peripheral circulatory failure.[1] At present there is no non-invasive measure of central haemodynamic status available routinely. The following cases seek to illustrate the possible role of both cerebral oximetry and stroke distance as measured by Doppler ultrasound in monitoring the critically ill patient non-invasively in the emergency department.

Methods

Cerebral oximetry—Cerebral oximetry is a spectroscopic means of measuring haemoglobin oxygenation similar to that used for pulse oximetry. A light source emitting light in the near infrared spectrum (650-1100 nm) in discrete wavelength bands is placed on the forehead to one side of the frontal sinuses. The emitted light is then scattered through the brain tissue of the frontal cortex and overlying structures. The light is refracted through this tissue, and the returning light waves are detected by sensors sited near the light source on the forehead. The wavelengths measured have specific absorption characteristics for oxyhaemoglobin and deoxyhaemoglobin, so that the absorption spectra reflect the ratio of oxyhaemoglobin to deoxyhaemoglobin in the blood in the brain tissue traversed.

There are two main differences between the measurements obtained by cerebral oximetry and pulse oximetry. Firstly, cerebral oximetry indicates the oxygen saturation of both venous and arterial blood in the brain (the reading is biased towards mixed venous saturation as the blood measured is 75% venous),[2] while pulse oximetry measures the oxygenation of arterial blood. Secondly, cerebral oximetry measurements are not affected by peripheral vasoconstriction, while this affects pulse oximetry in that readings may be unobtainable.[1] Cerebral oximetry has been validated against blood gas analysis for readings between 23% and 99% in vitro.[2]

Stroke distance—Doppler ultrasound can be used to measure blood flow in the aortic arch non-invasively. A probe is placed in the suprasternal notch to detect aortic blood flow. This gives a measure of stroke distance (the distance travelled by blood in the aorta with each ventricular contraction). Stroke distance measured in this way has been shown to correlate well with stroke volume and thus cardiac output measured using more invasive techniques.[4,5]

Stroke distance and cardiac output have been shown to correlate well over a wide range of values, independent of individual variations in aortic cross sectional area and patient body size.[6] Furthermore, under experimental conditions of simulated hypovolaemia, stroke distance measured as described was shown to be more sensitive than non-invasive blood pressure and more reliable than heart rate in detecting blood loss both in young adults and in the elderly.[7]

The aim of this study was to examine preliminary data recorded in isolated cases using cerebral oximetry (Invos 3100, Somanetics) and Doppler measurements of stroke distance (ODMI, Doptek), and to compare these reading with those obtained from non-invasive blood pressure monitoring (Dinamap, Critikon) and pulse oximetry (Lifestat 1600, Physiocontrol).

Case reports

CASE 1

A 49 year old male was admitted to the accident and emergency (A&E) department following a cardiac arrest from which he was successfully resuscitated. On arrival the patient had a palpable carotid pulse but no recordable blood pressure. There was no spontaneous respiratory effort and assisted ventilation was pro-

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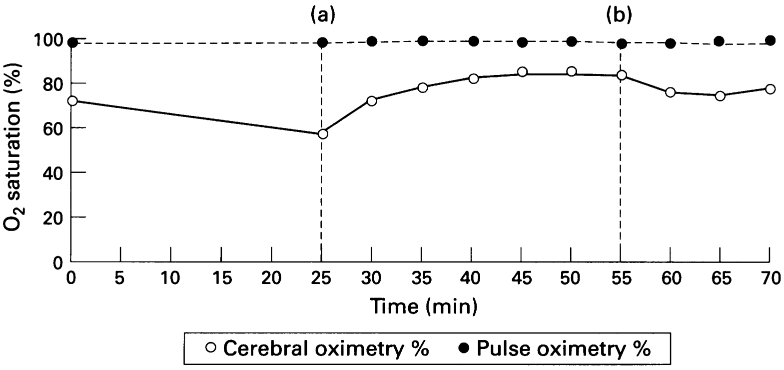

Variation of cerebral and pulse oximetry in case 2: (a) patient intubated; (b) patient extubated.

vided through an endotracheal tube. During the first 40 minutes after admission to A&E and later in the intensive care unit, pulse oximetry and blood pressure were unrecordable. The only recordable variables at this time were cerebral oximetry, stroke distance as measured by Doppler ultrasound, and ECG. The patient showed a gradual improvement of both cerebral oximetry (47% to 82%) and stroke distance (6 cm to 15 cm). Forty minutes after admission the first pulse oximetry and systolic blood pressure readings were obtained at 97% and 115 mm Hg respectively. Further monitoring showed a steady oxygen saturation of 98% on pulse oximetry (SpO_2) and of 80% on cerebral oximetry. During this time the blood pressure was maintained at approximately 160/90 mm Hg. The stroke distance continued to improve with a maximum reading of 24 cm. The patient was monitored on the intensive care unit overnight but died the next day.

CASE 2
A 49 year old male presented to the department having taken an overdose of an unspecified substance. On admission he had a Glasgow coma scale score of 3, a respiratory rate of 10/min, blood pressure of 120/60 mmHg, and pulse of 118 beats/min. Cerebral oximetry was 72%, SpO_2 99%, and PaO_2 of 42 kPa (313 mm Hg) (figure). A decision was made to perform gastric lavage after endotracheal intubation. Difficulty was encountered during intubation. Immediately post intubation pulse oximetry remained at 98%, while cerebral oximetry had dropped to 57%. The patient concurrently showed a hypotensive response, presumably to the anaesthetic drugs. Over the next 20 minutes cerebral oximetry gradually increased to 85%, while pulse oximetry remained unchanged. The patient was extubated when spontaneous respiration returned. After extubation the patient's cerebral oximetry dropped to 75%. There was no change in SpO2. There was no significant difference in blood pressure before and after extubation.

CASE 3
A 20 year old male presented acutely distressed to the A&E department following an overdose of methadone. He was cyanosed and confused. His respiratory rate was 28/min, blood pressure 130/60 mm Hg, and pulse 140 beats/min. Cerebral oximetry on admission was 57%, and SpO_2 was 70%. Blood gases showed a PaO_2 of 5.0 kPa (37.2 mm Hg) and a $PaCO_2$ of 10 kPa (74.9 mm Hg) During his stay in the emergency department both cerebral oximetry and SpO_2 remained low, but cerebral oximetry showed a gradual upward trend which was less consistently shown on pulse oximetry. A series of three arterial blood gas analyses in the department confirmed a gradual improvement in the patient's oxygenation during this time. Cerebral oximetry readings remained within the limits of reliability for the instrument but SpO_2 readings were below the lower limit of reliability for pulse oximetry.

CASE 4
A 48 year old male was seen in the department after falling from a height of 20 feet. On admission he was shocked with a blood pressure of 90/60 mm Hg and a prolonged capillary refill time. On admission SpO_2 was 99% and cerebral oximetry 74%. The patient was resuscitated with intravenous colloid, and his blood pressure gradually rose to 117/80 mm Hg. His stroke distance showed a parallel rise from 14 cm to 20 cm. Cerebral oximetry did not show this trend. The patient remained bradycardic at 50-60 beats/min throughout resuscitation.

CASE 5
An 18 year old male known to have gastric varices was admitted following a massive haematemesis. His blood pressure was 120/56 mm Hg, heart rate 60 beats/min, and he had a prolonged capillary refill time. On admission SpO_2 was 100%, cerebral oximetry 63%, and stroke distance 25 cm. Initial resuscitation included the administration of 2 units of Haemaccel intravenously, during which the patient's stroke distance increased to 38 cm. There was also a less marked increase in blood pressure. No such trend was seen in either cerebral oximetry or SpO_2. The patient remained bradycardic at 60 beats/min throughout resuscitation.

Discussion

The cases described illustrate the possible roles of both cerebral oximetry and stroke distance as measured by Doppler ultrasound in the monitoring of critically ill patients in the emergency department.

CEREBRAL OXIMETRY
Cerebral oximetry appears particularly useful in patients in whom pulse oximetry is either unrecordable or unreliable. In case 1, for example, pulse oximetry readings were unobtainable for the first 40 minutes of resuscitation because of vasoconstriction, while cerebral oximetry readings over this period produced results that were consistent with the patient's clinical condition and later followed the pulse oximetry readings. Case 3 shows that in patients in whom the degree of hypoxia renders pulse oximetry unreliable[1] the cerebral oxime-

ter may still produce readings within its working range[3] and thus provide clinically useful data.

Case 2 suggests that cerebral oximetry may detect episodes of transient hypoxia (for example those associated with difficult endotracheal intubation and extubation of the unconscious patient) that would be missed by pulse oximetry alone. The clinical significance of this is at present uncertain.

In contrast to its sensitivity in monitoring hypoxaemia, cerebral oximetry seems much less useful in detecting hypovolaemia. Although it has been shown to detect small differences in regional blood flow in the brain,[2 8] it does not appear able to detect early hypovolaemia (cases 4 and 5). The brain's autoregulatory mechanism maintains a consistent cerebral perfusion over a wide range of blood pressure and cardiac output[9] and so a global decrease in cerebral blood flow detectable by cerebral oximetry would be expected only late in hypovolaemia, unless their was a concomitant failure of autoregulation.

STROKE DISTANCE

In contrast to cerebral oximetry, stroke distance as measured by Doppler ultrasound proved to be an effective measure of hypovolaemia in cases 4 and 5. The change in stroke distance followed the same trend as that of blood pressure in these patients but was more marked. In case 5, the initial systolic blood pressure reading was within the normal limits for this patient while stroke distance was reduced, which indicated that the patient's cardiac output was low and the patient had compensated, thus maintaining his blood pressure. Both patients remained bradycardic throughout resuscitation, illustrating the unreliability of heart rate as a measure of hypovolaemia. Controlled studies have previously shown the effectiveness of stroke distance as an indicator of hypovolaemia.[7] Our cases provide some evidence of its usefulness in the clinical setting.

In case 1 Doppler ultrasound measurements of stroke distance were obtained for a significant period in early resuscitation during which non-invasive blood pressure was unrecordable. Initial blood pressure readings, when obtained, showed similar trends to that of stroke distance; thus stroke distance gave an indication of the patient's haemodynamic state earlier than blood pressure. The gradual increase in the patient's stroke distance in the early phase of resuscitation was mirrored by an improvement in the patient's clinical condition.

In summary, these cases show that cerebral oximetry may provide useful information on tissue oxygenation in some patients in whom pulse oximetry cannot be used, but appears less useful in detecting hypovolaemia. Stroke distance, however, has proved a useful indicator of early hypovolaemia in the clinical setting, even in the absence of significant hypotension or tachycardia.

CONCLUSION

The five cases described provide evidence that both cerebral oximetry and stroke distance as measured by Doppler ultrasound may be useful adjuncts to the monitoring of critically ill patients in the emergency setting in specific situations. It should be noted that both cerebral oximetry and stroke distance appear to be more useful in indicating trends in individual patients rather than in giving absolute values. This report provides useful clinical anecdotes but must be followed by more carefully controlled clinical trials to ascertain the indications for and benefits of this type of monitoring in accident and emergency departments.

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